A Multilayer Active Hybrid-Ring Using Ground-Slot Coupling Technique

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Abstract — **A ground-slot coupling technique is applied to design a novel multilayer active hybrid-ring power divider. The prototype consists of three ground slots to couple signal between circuit layers, and two single-stage HEMT amplifiers to boost the coupled signal. It is tested in C-band with 40% -3dB bandwidth. At 5GHz center frequency, it has 8dB small-signal gain and 10dBm output P1dB.**

I. Introduction

A broadband power divider in the form of five-ports hybrid ring is reported in [1]. The bandwidth and the phase difference are further improved in [2]. All these hybrid-ring power dividers are passive devices.

To have a broadband hybrid-ring power divider with positive signal gain, an amplifying circuit can be introduced. However, the amplifying circuit takes up valuable space for the hybrid-ring. Therefore a ground-slot coupling technique similar to [3] and [4] is introduced in this paper. This technique allows signal coupling from the top microstrip line to the bottom microstrip line, and vice versa. As a result, the active amplifying circuit can be placed on the other side of the passive hybrid-ring circuit.

This combination forms a multilayer structure, which is compact and versatile. Moreover, there is basically no limitation to the number of amplifiers used, and so the signal gain can be increased. If many of such multilayer dividers are cascaded together to form a lattice structure, the power output can be risen significantly. On top of all the above advantages, the ground-slot coupling for the multilayer power divider is cheap and easy to fabricate.

In this paper, a novel ground-slot combination is designed for the multilayer power divider. It has broad bandwidth and low loss. Then a broadband passive hybrid-ring is modified from DESIGN(I) in [2]. For the active device wise, a general purpose Fujitsu FHC40LG package transistor is applied to build a single-stage amplifier. Together with the transistors, all the transistor matching networks and bias circuits are placed at the back of the passive hybrid-ring coupler in the prototype. At the end, this prototype is built and tested to verify with the simulation results. More details are given in the following sections.

II. Ground-Slot Coupling Technique

Energy coupled through ground aperture has been used widely in microstrip antenna designs [5-7]. The shapes of the aperture can be circular, rectangular, U-slot or others depending on the application criteria. Apart from coupling energy, the aperture acts as a tuning element.

In this report, a ground-slot type of aperture is designed to couple energy from one microstrip line to another as shown in Fig. 1. Both microstrip lines are terminated as open stubs. Together with the stub length, the slot size, shape and orientation are adjusted to ensure that the maximum coupling is achieved.

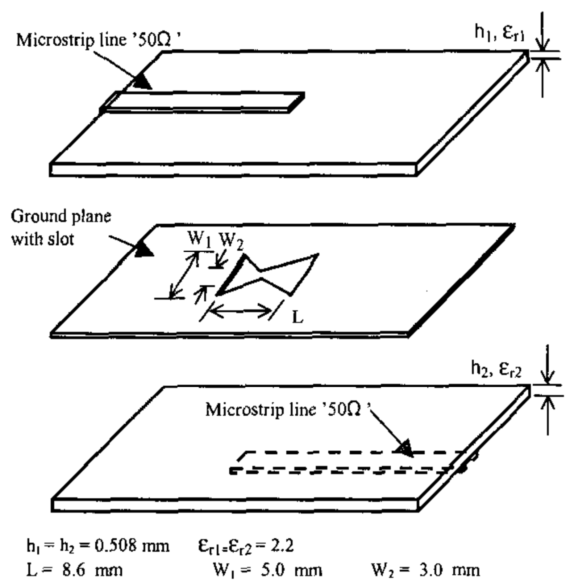

Fig. 1. 3-D structure of a ground-slot coupling.

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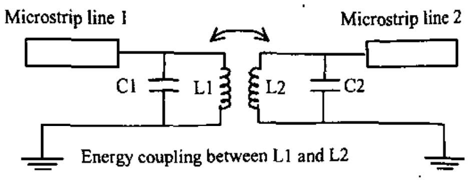


Fig. 2. A Simple model for the ground-slot coupling.

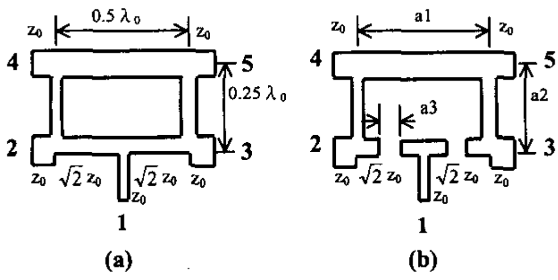
To illustrate the ground-slot coupling technique, a simple model for a slot is shown in Fig. 2. It comprises two inductors and two capacitors. Signal from microstrip line 1 reaches L1 and then couples across to L2 before going out to microstrip line 2. According to the size, the shape and the orientation of the slot, values of C1 and C2 vary with L1 and L2 respectively. Each LC pair acts as a tuning device for the impedance matching between microstrip lines.

During the design stage, an electromagnetic simulation software called IE3D from Zeland Software Inc is used. There are two types of slots for this design, which are bowtie-shape and trapezium-shape slots (refer to Fig. 6 for the allocation). The size, the shape and the orientation of the slot are carefully designed and optimized to achieve its best performance for this prototype. The individual bandwidth performance at −10dB return loss is 69% and 44% respectively.

III. Active Hybrid-Ring Power Divider

A passive hybrid-ring power divider is selected from [2], and is extended for the ground-slot coupling purpose. The diagrams of the original and the modified hybrid-ring structures are shown in Fig. 3.

From Fig. 3(b), it can be seen that there are two breaking paths at the $\sqrt{2}\,Z_0$ impedance branches. Each breaking path is catered for the coupling signal through the ground-slot as illustrated in Fig. 4.



a1 = 22.4mm ; a2 = 11.2mm ; a3 = 6.5mm

Fig. 3. a) Original hybrid ring and b) Modified hybrid ring.

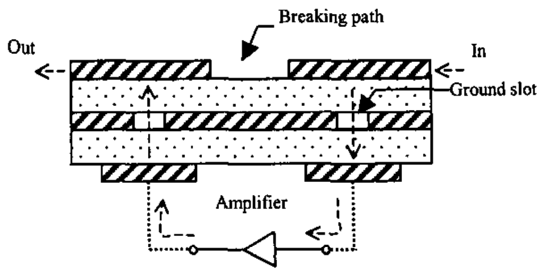


Fig. 4. Breaking path at $\sqrt{2}$ Zo branches.

Next a single-stage amplifier is designed by using Fujitsu FHC40LG. This transistor is a general-purpose package transistor in HEMT technology. The schematic diagram of this single-stage amplifier is shown in Fig. 5. Both design and simulation are carried out by using HP ADS simulation software. The amplifier has a -3dB bandwidth of 47%.

Finally, the simulation data of the ground-slot structure is exported from IE3D to ADS. Then it is combined with the modified hybrid ring and the amplifiers. The overall topology presented in Fig. 6 is simulated and fine-tuned in ADS again. The final optimized dimensions for the hybrid ring are indicated in Fig. 3.

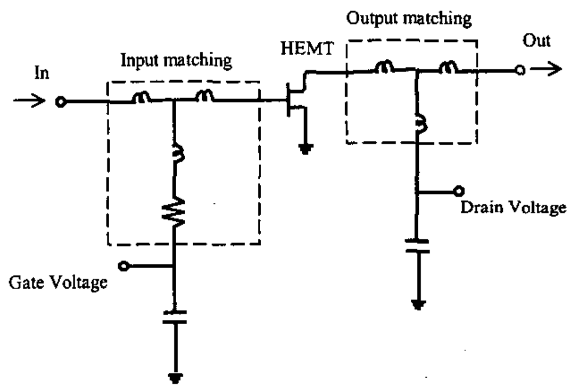


Fig. 5. Schematic diagram of the amplifier block.

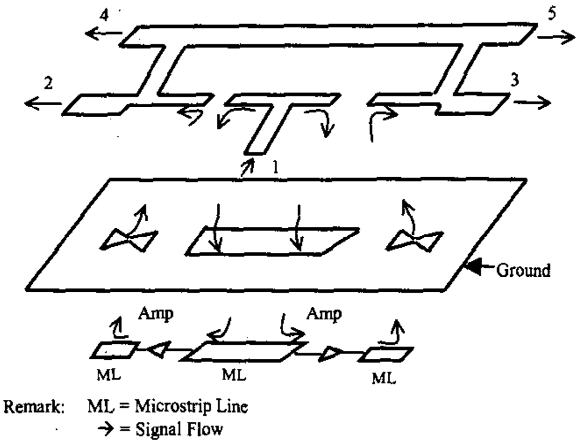


Fig. 6. Overall topology of the multilayer power divider.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

A prototype of the multilayer active hybrid-ring power divider is fabricated. It consists of two PCBs (Printed Circuit Boards) lying back to back with each other. The top PCB is fabricated with the passive hybrid-ring coupler. The bottom PCB has two single-stage amplifiers, one amplifier for each branch. Both PCBs are made of Duroid substrate with the permittivity, ε_r =2.2 and the thickness of 0.508mm.

The small-signal S-parameters of the power divider are measured with the HP8510C Network Analyzer. The output power is obtained by using the Rohde & Schwarz SMP02 signal generator and the HP8593E spectrum analyzer. The results of gain S21, return loss S11 and S22, as well as output power characteristics of the power divider are shown in Fig. 7. The results of port 3 are very similar to that of port 2 and therefore are not shown here.

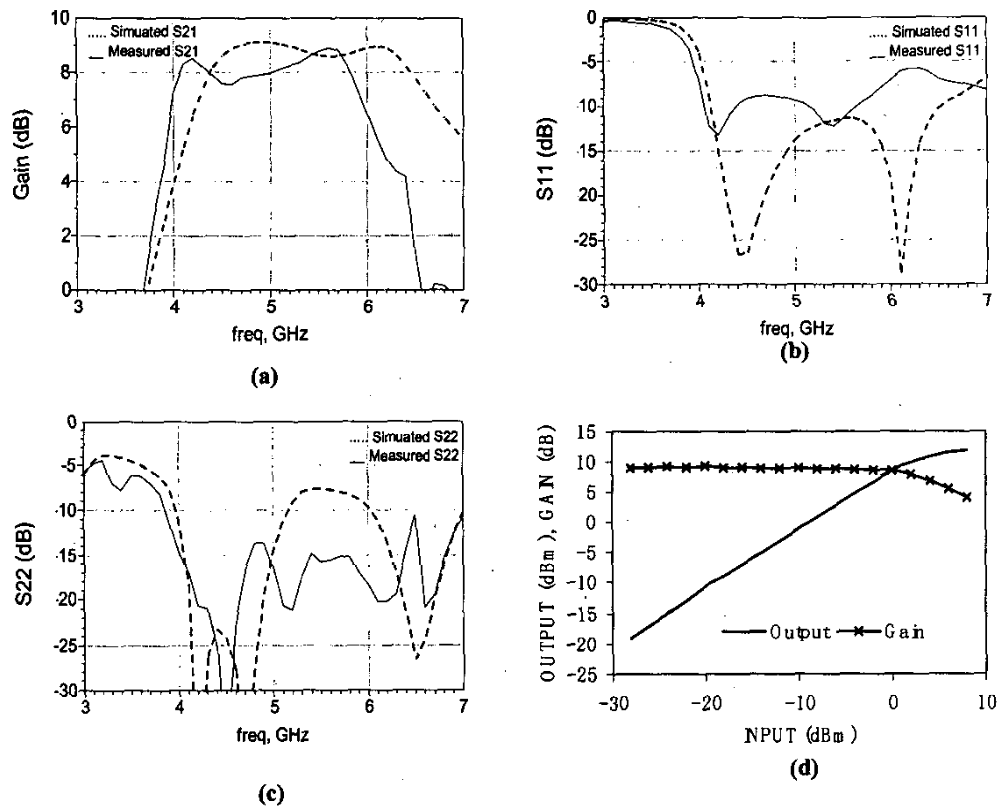


Fig. 7. Simulated and measured results of the multilayer power divider. (a) Small-signal gain S21. (b) Return loss S11. (c) Return loss at Port 2 (or Port 3). (d) Output level and gain for different input level at 5GHz.

The measured data presented in Fig. 7 agrees pretty well with the simulated data. The -3dB gain bandwidth is about 40% (4.0 – 6.0GHz) with the small-signal gain of 8dB. The output P1dB compression point is about 10dBm at center frequency.

This prototype has demonstrated that signal is divided, coupled and boosted from the input port to the output ports. The incoming signal from port 1 at the top PCB is coupled through the ground slot and amplified by the amplifier block at the bottom PCB. This amplified signal is then coupled through another ground slot and channeled to port 2 at the top PCB. The signal flow is same for port 3. Both amplitude and phase of the signal at port 2 and port 3 are similar. If compared to a hybrid ring reported in [2], the phase difference between port 2 and port 3 has an obvious difference in this prototype. It is mainly due to the non-identical characteristics of the transistors used.

V. Conclusion

In conclusion, a ground-slot coupling technique is applied to build a novel multilayer active power divider made of modified hybrid ring. This power divider has proven to achieve 8dB gain, 40% bandwidth and 10dBm output P1dB with center frequency of 5GHz.

This technique enables the construction of the amplifying block on the other side of the hybrid-ring circuit. It creates a multilayer structure which is compact, cheap and easy to fabricate.

Acknowledgement

The author would like to acknowledge the consistent support and understanding from his wife during his work for this paper.

References

[1] G. F. Mikucki and A. K. Agrawal, "A broad-band printed circuit hybrid ring power divider," *IEEE Trans. Microwave Theory and Tech.*, vol. 37, no. 1, pp. 112-117, Jan. 1989.

[2] B. Ooi, W. Paler, and M. S. Leong, "Broad-banding technique for in-phase hybrid ring equal power divider, " *IEEE Trans. Microwave Theory and Tech.*, vol. 50, no. 7, pp. 1790-1794, Jul. 2002.

[3] C. Chen, M. Tsai, and N. G. Alexopoulos, "Optimization of aperture transitions for multi-port microstrip circuits," *1996 IEEE MTT-S Digest*, pp. 711-714, 1996.

[4] C. Ho, L .Fan, and K. Chang, "Slot-coupled double-sided microstrip interconnects and couplers," *1993 IEEE MTT-S Digest*, pp. 1321-1323, 1993.

[5] D. M. Pozar, "Microstrip antenna aperture-coupled to a microstripline," *Electronics Letters*, vol 21, no.2, pp 49-50, Jan. 1985.

[6] Y. W. Jang, "Broadband T-shaped microstrip-fed U-slot coupled patch antenna," *Electronics Letters*, vol 38, no.11, pp 495-496, May 2002.

[7] K. Wong, *Compact and Broadband Microstrip Antennas*, New York: Wiley, 2002.